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LOAD-CARRYING CAPACITY AND STATE OF EFFORT OF TUBES MADE OF GLASS AND BASALT FIBRE REINFORCED POLYMER FILLED WITH CONCRETE

Abstract

Concrete Filled Tubes (CFT) made of composite reinforced with glass and basalt fibres were subjected to axial compression in experimental tests. Columns height and loading method (either through concrete core or through entire cross-section) varied. As the experiments indicate, the load-carrying capacity is higher in case of loading through the entire section. Post-critical behaviour of slender columns is better (more safe) than stub ones. Small number of the conducted experiments does not let to draw reliable conclusion.

1 Introduction

Structures made of concrete reinforced or confined with composite materials do not belong to engineering tradition. This way of constructing is as new as the composite materials themselves. However, it has some advantages and is an interesting alternative for monomaterial structures and reinforced concrete structures. The most obvious advantage is a high corrosion resistance.

In some specific applications the high corrosion resistance of composite tubes filled with concrete may eliminate CFST (Concrete Filled Steel Tube) columns. Similarly as CFST columns, composite tubes filled with concrete compared to reinforced concrete structures are able to resist higher load in post-critical region, though occurring of high deformations. Moreover, the destruction mechanism is not so immediate. The behavior of these columns before destruction is plastic, ductile, which is good for construction safety. That is why the potential scope for applications of CFT (Concrete Filled Tubes) columns are countries of high seismic activity (e.g. Japan, United States, China). This column type compared to steel columns is less sensible on vibrations because of their mass.

CFT columns can offer many other advantages, which make them popular also in European countries. These columns are comfortable in realisation, because they do not require any scaffolding and additional internal reinforcement. It enables an increase in speed of construction. CFT columns are easy to adapt to prefabrication and to form simple standardized connections with beams and other columns.

Concrete Filled Steel Tubes are well known and popular in civil engineering since many years. The art of their constructing and calculating is in detail standardized in many national codes as well in Eurocode 4. It is also well verified during dozens of years of building practice [1], [2], [3], [4], [5]. There are neither European nor national codes dedicated to Concrete Filled Composite Tubes (CFCT) columns.

2 Calculating of Concrete Filled Tubes

As there are not standardized calculation methods for Concrete Filled Composite Tubes, authors used procedures for columns made of Concrete Filled Steel Tubes in order to analyse results of own experiments, which are presented in the next chapter.

The Eurocode 4 [2] method of calculating is presented below. The load which is applied to a specified column N_{Sd} cannot exceed load-bearing capacity of this column:

$$N_{Sd} < \chi \cdot N_{pl.Rd} \quad (1)$$

The buckling factor χ is to be taken on the basis of buckling curve ”*a*” or “b” from *Eurocode 3.* It depends on relative slenderness $\bar{\lambda}$ of CFT column. The value of $N_{pl.Rd}$, which is design loading capacity of composite section, is calculated from the formula consisting of two augends:

$$N_{pl.Rd} = \eta_{ao} \cdot A_a \cdot f_{yd} + A_c \cdot f_{cd} \left(1 + \eta_{co} \frac{t}{d} \frac{f_{yk}}{f_{ck}} \right) \quad (2)$$

The first augend of this formula is connected with the tube, the second with concrete core. The symbols used above mean as follows:

- A_a, A_c - cross-sectional area of tube and concrete core, respectively
- f_{yd}, f_{cd} - design values of compression strength of materials used for tube and concrete core, respectively.

Both augends of the $N_{pl.Rd}$ formula (2) hold following coefficients:

- η_{ao} - coefficient reducing loading capacity of tube due to biaxial state of stress (compression in longitudinal direction and tension in circumferential direction)
- $\left(1+\eta_{co}\frac{t}{d}\frac{f_{yk}}{f_{ck}}\right)$ - coefficient increasing loading capacity of the concrete core due to triaxial state of stress (permissible only if $\bar{\lambda}$ ≤0,5)

In these formulae following symbols were used:

η_{ao}, η_{co} - coefficients depending on relative slenderness $\bar{\lambda}$ of CFT column

t - tube thickness

d - external diameter of tube

f_{yk}, f_{ck} - characteristic values of compression strength of the tube material and of the column concrete, respectively

In case when the part of loading capacity connected with the concrete core exceeds 80 % of the whole loading capacity, Eurocode 2 (Concrete structures) should be used.

3 Authors' experimental investigation

3.1 Description of test samples

There were six columns investigated, from which four were tubes filled with concrete and two were empty tubes. Tubes were made as composite and consisted of basalt and glass fibres in vinyloester matrix. Properties and percentage of the fibers are presented in Table 1. The internal diameter of tubes was equal to 200 mm, the wall thickness was equal to 6 mm.

Fibres	Percentage	Linear mass density	Thickness
	[%]	[tex]	[μm]
Glass	60	2400	7-8
Basalt	40	2520	13

Table 1: Properties of the fibres used in tube production

The variables in experimental investigations was column height (2170 or 1170 mm) and loading method: through the concrete core or through the entire section.

Compressive strength of concrete f_{cm} was determined on six cylindrical specimens 150/300 mm and was equal to 76 MPa. Tube composite compressive strength was tested on four specimens, which were cut from the empty composite tubes. The length of specimens was two times higher than internal tube diameter and was equal to 400 mm. The obtained tube composite strength was equal to 83,8 MPa. Area of composite tube related to area of concrete core in column cross-section was equal to 12,4%.

The most important geometrical and technical data of all investigated columns are collated in Table 2.

Column number	Theoretical height	Column type	Loading method	Experimental load capacity
	[mm]			[kN]
1	1170	empty tube	-	275,7
2	1170	tube filled with concrete	concrete core	2478,9
3	1170	tube filled with concrete	entire section	2567,3
4	2170	empty tube	-	279,9
5	2170	tube filled with concrete	concrete core	2463,3
6	2170	tube filled with concrete	entire section	2577,1

Table 2: Data of investigated columns

3.2 Experimental setup

Every column was subjected to axial load. Every support, upper and lower, was jointed. These joints were ball bearings (fig. 1), which ensured, that each end of the column could rotate in every direction. Distance between bearing base and ball axis was equal to 85 mm. Therefore theoretical column height was 170 mm bigger than the real one. That is why values of theoretical column height collated in Table 1 difference from real heights which were 1000 mm and 2000 mm.

3.3 Completion of experiments

All investigated columns were loaded by displacement control. Compressive force was slightly decreasing during separate load levels while the press piston was stopped and did not move (fig. 5). The loading velocity varied from 0,2 mm/ min to 1,0 mm/min. Duration of every test was equal to minimum 20 minutes and maximum 90 minutes.

Load was applied to CFT columns in two possible ways: either through the concrete core without participation of the composite tube or through the entire cross-section i.e. concrete core and composite tube at the same time.

During tests measurements of longitudinal and circumferential strains of composite tube have been taken. Six strain gauges were installed in the middle cross-section of every column: three of vertical and three of circumferential attitude (fig. 1).

Fig. 1: Experimental stand with column L_o=1170 mm, ball bearing, strain gauges: v-vertical, h-horizontal

4 Analysis of the experimental results

4.1 Fracture modes

All CFT columns fractured by global buckling, with a visible deflection (fig. 2). Both empty tubes fractured locally (fig. 2).

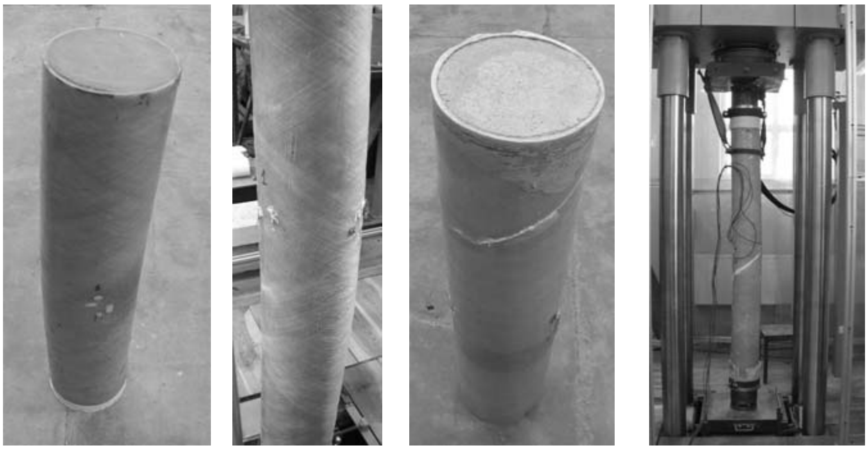

Fig. 2: Fracture modes of investigated columns: CFT L_0=1170 mm and 2170 mm, empty tubes L_0=1170 mm and 2170 mm

4.2 State of effort

As fig. 3 as an example indicates, all circumferentially and longitudinally installed strain gauges measured similar quantities. As expected the longitudinal effort was compression and the circumferential effort was tension. The compression was at every moment of test about three times higher than the tension.

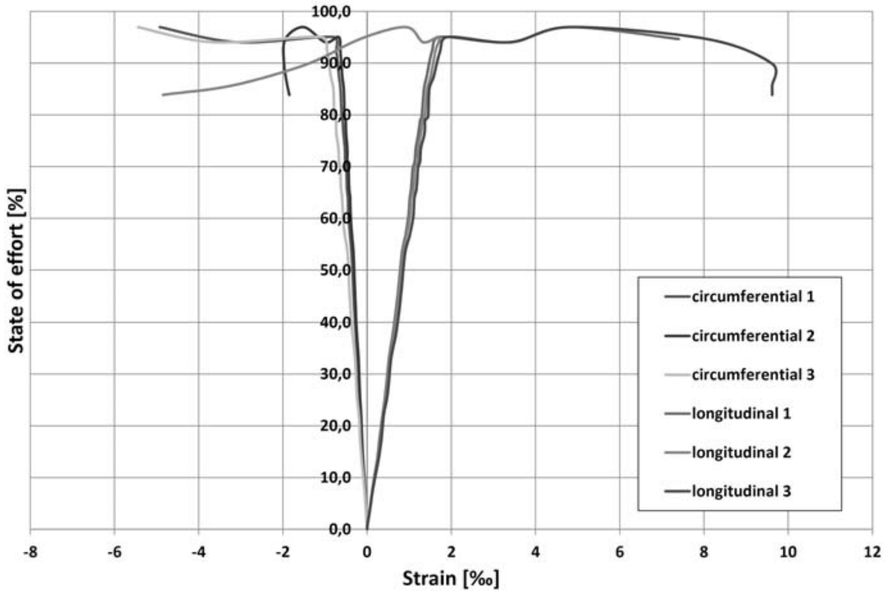

Fig. 3: State of effort versus strain obtained for column Lo=1170 mm, filled with concrete, loaded through entire section

4.3 Load-carrying capacity

The highest load-bearing capacity was obtained for the columns loaded through entire cross-section (fig. 4).

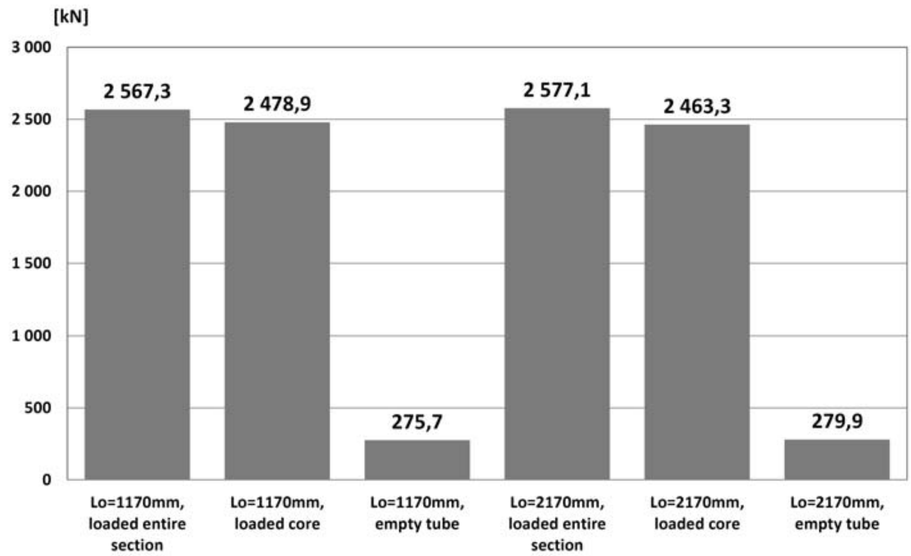

Fig. 4: Load-carrying capacities of investigated columns

The difference was equal to 3,5% (stub columns) and 4,5% (slender columns). There were only slight differences in load-bearing capacities of stub and slender columns, which were loaded in the same way.

The prediction of Eurocode-4 formulae for load-carrying capacity was satisfying for the group of four investigated composite columns (Table 3), though the part of load-carrying capacity connected with the concrete was higher (88 % of the whole loading capacity) than it is required in Eurocode 4 (see chapter 2).

Column No. from Table 2	Relative slenderness	Decreasing factor for tube strength due to biaxial state of stress	Increasing factor for concrete strength due to triaxial state of stress	Global buckling factor χ (curve "a")	Load-carrying capacity according to EC4	N_{exp} / N_{calc}
	$\overline{\lambda}$	η_{ao}	$\left(1+\eta_{co}\frac{t}{d}\frac{f_{yk}}{f_{ck}}\right)$		N_{calc} [kN]	
2	0,383	0,942	1,010	0,96	2 600	0,95
3	0,383	0,942	1,010	0,96	2 600	0,99
5	0,711	1,000	1,000	0,84	2 285	1,08
6	0,711	1,000	1,000	0,84	2 285	1,13
					mean:	1,06

Table 3: Comparison between calculated and experimental load-carrying capacities for investigated columns

4.4 Post-critical behaviour

The highest post-critical load-bearing capacity was obtained for the slender CFT columns (fig. 5). The empty tubes fractured suddenly, without any signals before.

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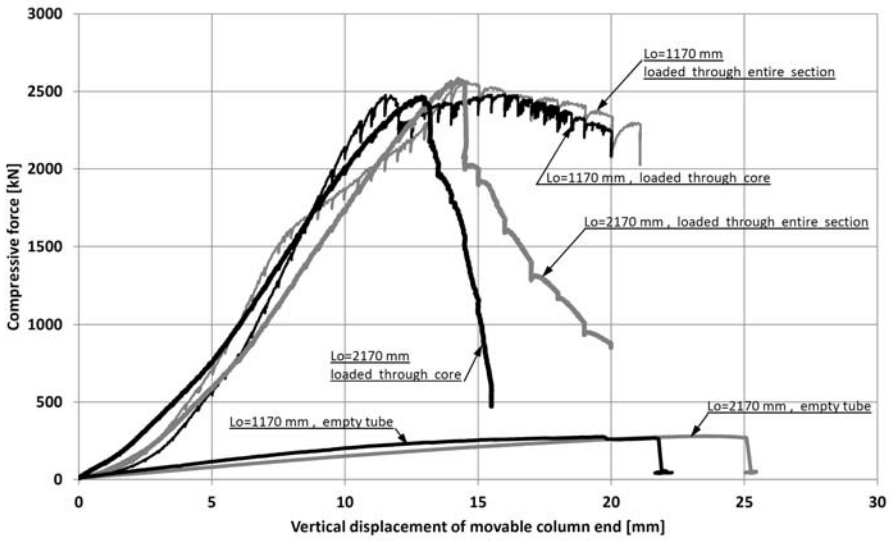

Fig. 5: Load-displacement relations of investigated columns

References

[1] Abramski M. Experimental Investigation of Axially Loaded CFST Columns. Thesis for the Degree of Doctor of Philosophy, Gdansk University of Technology, Gdansk, Poland, 2006 (in Polish)

[2] EN 1994-1-1: 2004. Eurocode 4. Design of composite steel and concrete structures, Part 1-1: General rules and rules for buildings.

[3] Fam A.Z., Rizkalla S.H.: Behavior of Axially Loaded Concrete-Filled Circular Fiber-Reinforced Polymer Tubes. ACI Structural Journal, 5-6/2001.

[4] Kondrat J.: Experimental investigation on effort and load-bearing capacity of CFST columns. Diploma work. Gdansk University of Technology. Faculty of Civil and Environmental Engineering, 2004 (in Polish)

[5] Korzeniowski P., „Confined concrete columns. Experimental tests and theory". Thesis for the Habilitation Degree, Gdańsk University of Technology, 2000 (in Polish).